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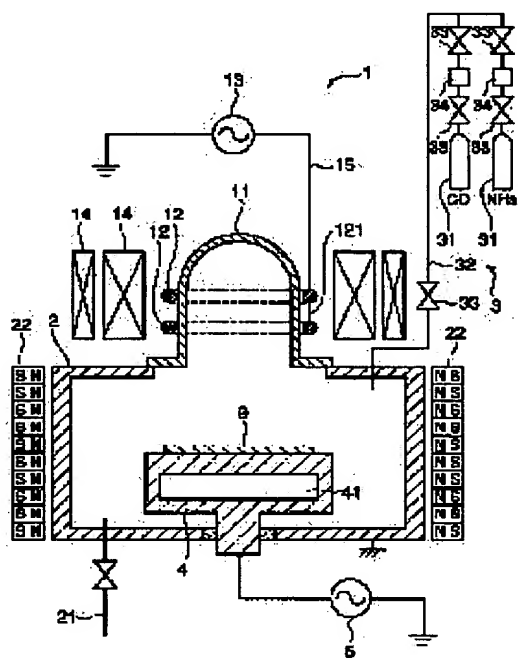
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NAKATANI ISAO**(54) METHOD FOR ETCHING MAGNETIC MATERIAL AND PLASMA ETCHING DEVICE****(57)Abstract:**

**PROBLEM TO BE SOLVED:** To extremely heighten an etching speed of a magnetic thin film using a mixed gas of carbon monoxide with ammonia and to make it possible to make this kind of technology practicable for production of a thin film magnetic head and the like.

**SOLUTION:** A gaseous mixture of carbon monoxide gas and ammonia gas is introduced to a treating chamber 2 by means of a gas introducing system 3 and plasma of these gases is formed by a plasma source 1 forming helicon wave plasma. On a surface of a target 9 made of a magnetic material consisting of nickel, iron and cobalt and an alloy, a nitride and an oxide containing at least one metal selected from these metal elements or an intermetallic compound containing at least one metal selected from these metal elements, carbonyl compounds are formed by reactions with carbon monoxide and etching is carried out by evaporation of the carbonyl compounds. The plasma has  $1 \times 10^{11} \text{ cm}^{-3}$  density and a large quantity of carbon monoxide gas having large mass is ionized and incident on the surface of the target 9. Thereby the etching speed is heightened.

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**CLAIMS**


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[Claim(s)]

[Claim 1] The etching approach of the magnetic material characterized by forming the plasma of the mixed gas of ammonia and a carbon monoxide in the space which overlooks the front face of the object which is the magnetic material which consists of nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, an oxide, or the intermetallic compound containing these at least one by three or more [ 1x10<sup>11</sup>cm - ] consistencies, and etching the front face which is said magnetic material.

[Claim 2] The processing chamber equipped with the exhaust air system, and the gas feed system which mixes and introduces ammonia gas and carbon monoxide gas in a processing chamber, The source of the plasma which supplies energy to the introduced gas and forms the plasma of these gas by three or more [ 1x10<sup>11</sup>cm - ] consistencies, A front face Nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, or an oxide, Or the plasma etching system characterized by having the object electrode holder which holds the object which is the magnetic material which consists of the intermetallic compound containing these at least one in the location where the front face is etched by said plasma.

[Claim 3] Said source of the plasma is a plasma etching system according to claim 2 characterized by being what forms the helicon wave plasma.

[Claim 4] Said source of the plasma is a plasma etching system according to claim 2 characterized by being what forms the magnetron discharge plasma.

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## DETAILED DESCRIPTION

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[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the etching technique used suitable for especially manufacture of the thin film magnetic head about the etching technique of a magnetic material.

[0002]

[Description of the Prior Art] The technique which etches a magnetic material is an important technique in manufacture of the thin film magnetic head carried in a magnetic disk drive etc. Many frame plating is used in manufacture of the thin film magnetic head. Drawing 4 is drawing explaining frame plating as a conventional technique. First, the frame resist 901 is formed in the front face of a substrate 90 by the predetermined pattern ( drawing 4 (1)), and a magnetic thin film 902 is formed by plating to the frame resist 901. ( Drawing 4 (2)) . And as the magnetic thin film 902 inside the frame resist 901 is covered, the up resist 903 is formed ( drawing 4 (3)). Wet etching is carried out with an etching reagent in this condition, the magnetic thin film 902 of the outside of the frame resist 901 is removed, and that Gokami section resist 903 and the frame resist 901 are exfoliated. Consequently, the magnetic thin film 902 of a predetermined pattern is obtained ( drawing 4 (4)).

[0003] To such frame plating, the limitation is pointed out by making detailed-ization of the thin film magnetic head accompanying the densification of a magnetic disk into a background. Although a thick frame resist needs to be formed of frame plating, it is because the formation becomes difficult by the detailed pattern.

[0004] Etching a magnetic thin film directly by the dry etching method, and obtaining the magnetic thin film of a predetermined pattern is examined under such circumstances. One approach is the approach of making carry out incidence of the ion to a magnetic thin film, and etching it into it. For example, incidence of the ion can be carried out from the plasma of argon gas, or it is possible to irradiate the ion beam of an argon and to etch it. However, such an approach is physical etching and is bad. [ of the selectivity over other ingredients, such as a substrate and a mask, ] Moreover, generally an etch rate is also low and has a problem in respect of productivity.

[0005] Then, applying reactive ion etching (ReactiveIon Etching, RIE) to etching of this kind of magnetic material is examined as chemical etching. Etching of the magnetic material by RIE is reported by J.Vac.Sci.Technol.A4 (4), 1841 (1986), and Appl.Phys.Lett.67(21) and 3194 (1995), for example. However, in these reports, an etch rate is as low as the following by 10nm/.

[0006] Recent years come and the example from which a part for etch rate/of 300nm of a nickel-Fe alloy was obtained is reported by by using chlorine gas for Appl.Phys.Lett.71(9) 1255 (1997) etc. However, by etching of the magnetic material by chlorine gas, the problem of the corrosion by chlorine remaining to an after corrosion, i.e., a front face, tends to occur. Although an after corrosion can be prevented by processing washing with water after etching etc., it has the problem on which a routing counter increases.

[0007] The approach indicated by the patent No. 2677321 official report is one of those use neither the chlorine leading to an after corrosion, nor a fluorine. In this official report, it is supposed by using the gas which mixed ammonia (NH<sub>3</sub>) with the carbon monoxide (CO) that a part for etch rate/of 24.4nm of a part for /and the etch rate Co-Cr alloy of 35nm of a nickel-Fe alloy was obtained, respectively.

[0008]

[Problem(s) to be Solved by the Invention] As mentioned above, it is CO and NH<sub>3</sub>. It is possible to etch the magnetic thin film which consists of nickel suitable for the thin film magnetic head etc., Co, or Fe, without causing the problem of an after corrosion by using mixed gas. However, the etch rate is about 24-35nm/minute, and is still low. It is necessary to etch thickness of no less than 2 micrometers in manufacture of the thin film magnetic head. Therefore, the present etch rate will take the time amount for about 50 - 80 minutes, and it is count still far from utilization. This invention is accomplished in consideration of such a situation, makes it possible to etch at the high rate far exceeding the present condition in etching of the magnetic thin film using the mixed gas of CO and NH<sub>3</sub>, and has technical meaning of opening the way of utilization of this kind to manufacture of the thin film magnetic head etc. of technique.

[0009]

[Means for Solving the Problem] In order to solve the above-mentioned technical problem, invention of this application according to claim 1 forms the plasma of the mixed gas of ammonia and a carbon monoxide in the space which overlooks the front face of the object which is the magnetic material which consists of nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, an oxide, or the intermetallic compound containing these at least one by three or more [ 1x10<sup>11</sup>cm<sup>-2</sup> ] consistencies, and has the configuration of etching the front face which is said magnetic material. In order to solve the above-mentioned technical problem,

moreover, invention according to claim 2 The processing chamber equipped with the exhaust air system, and the gas feed system which mixes and introduces ammonia gas and carbon monoxide gas in a processing chamber, The source of the plasma which supplies energy to the introduced gas and forms the plasma of these gas by three or more [ 1x10<sup>11</sup>cm<sup>-3</sup> ] consistencies, A front face Nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, or an oxide, Or it has the configuration of having the object electrode holder which holds the object which is the magnetic material which consists of the intermetallic compound containing these at least one in the location where the front face is etched by said plasma. Moreover, in order to solve the above-mentioned technical problem, invention according to claim 3 has the configuration that said source of the plasma is what forms the helicon wave plasma, in the configuration of above-mentioned claim 2. Moreover, in order to solve the above-mentioned technical problem, invention according to claim 4 has the configuration that said source of the plasma is what forms the magnetron discharge plasma, in the configuration of above-mentioned claim 2.

[0010]

[Embodiment of the Invention] Hereafter, the gestalt of operation of the invention in this application is explained. First, the operation gestalt of invention of claim 2 and claim 3 is explained. Drawing 1 is the transverse-plane sectional view showing the outline configuration of the plasma etching system which is the operation gestalt of invention of claim 2 and claim 3.

[0011] The plasma etching system shown in drawing 1 is equipment which etches the front face of an object by the helicon wave plasma. The helicon wave plasma attracts attention as what can form the plasma of high density also by the comparatively low pressure. Although the mechanism of the energy transfer in the helicon wave plasma has the place which is not sufficiently clear, it is thought that the plasma is formed by kinetic energy being given to an electron from a RF according to the phenomenon called Landau damping. That is, since it is the same as it saw from the electron and the helicon wave has stopped when the rate of the electron which moves while rotating by the field is equal to the phase velocity of a helicon wave, it is continuously accelerated from a helicon wave, an electron absorbs energy, and the plasma of high density is formed of this.

[0012] When the configuration of equipment is explained concretely, the equipment shown in drawing 1 is CO and NH<sub>3</sub> in the source 1 of the plasma which generates the helicon wave plasma, the processing chamber 2 which the plasma which the source 1 of the plasma generated diffuses, and the processing chamber 2. It mainly consists of object electrode-holder 4 grades which hold the object 9 of etching in the gas feed system 3 which introduces mixed gas, and the predetermined location in the processing chamber 2.

[0013] The source 1 of the plasma consists of RF generator 13 for plasma which generates the high-frequency power supplied at the antenna 12 which carries out induction of the helicon wave, and an antenna 12 in the dielectric container 11 airtightly connected as the building envelope was open for free passage to the processing chamber 2, and the dielectric container 11, and magnet 14 grade which sets up a predetermined field in the dielectric container 11. An end is opening, and the dielectric container 11 is the member of the shape of a cylinder which the other end has closed in the shape of a semi-sphere, and is formed with the quartz etc. Opening is prepared in the upper wall section of the processing chamber 2, and as opening of the end of the dielectric container 11 and opening of this upper wall section are made to open for free passage, the dielectric container 11 is airtightly connected to the processing chamber 2.

[0014] The thing which RF generator 13 for plasma makes generate a 13.56MHz RF is used. An antenna 12 is the configuration almost in a circle which the cylindrical or band-like member was rounded off [ configuration ], and made a little both ends estrange, and it is arranged on the dielectric container 11 and the same axle so that the dielectric container 11 may be surrounded. The antenna 12 is formed in two shaft orientations of the dielectric container 11, and both both ends are electrically connected with the junction rod 121, respectively.

[0015] The high periphery power source 13 for plasma and the antenna 12 are connected through the non-illustrated adjustment machine by transmission line 15 like a coaxial cable. When the RF which RF generator 13 for plasma generated is supplied to two antennas 12 by the transmission line 15, at two antennas 12, the current of the reverse sense flows mutually. Consequently, induction of the helicon wave (circularly-polarized wave of the right-handed rotation same here as a whistler wave) is carried out to the interior of the dielectric container 11. in addition, alienation of two antennas 12 — spacing is selected so that the phase velocity of a helicon wave may become the optimal in relation with electronic passing speed.

[0016] Moreover, a magnet 14 is for setting up a field parallel to the travelling direction of a helicon wave in the dielectric container 11. Magnetic field strength is made into about 100 gauss near the medial axis of the dielectric container 11. With this operation gestalt, a magnet 14 is an electromagnet and is formed on [ two ] the same axle. The outside magnet 14 is mainly formed for the inside magnet 14 for adjustment of a field configuration for helicon wave plasma formation.

[0017] A gas feed system 3 is the bomb 31 which accumulated CO gas, and NH<sub>3</sub>. It mainly consists of a bulb 33 prepared on the piping 32 which connects the bomb 31 which accumulated gas, each bomb 31, and the processing chamber 2, a flow regulator 34, a non-illustrated filter, etc. CO gas and NH<sub>3</sub> Each flow regulator 34 can adjust now the mixing ratio and flow rate of gas. The processing chamber 2 is the airtight vacuum housing equipped with the non-illustrated gate valve. The exhaust air system 21 attached to the processing chamber 2 is equipped with a diffusion pump, a turbo molecular pump, etc., and is constituted possible [ exhaust air of the inside of the processing chamber 2 ] to the predetermined ultimate-pressure force.

[0018] As shown in drawing 1 , many magnets 22 for side attachment walls are formed in the outside of the side attachment wall of the processing chamber 2. the magnets 22 for side attachment walls differ mutually with the

magnets which the magnetic pole of Men who faces the side attachment wall of the processing chamber 2 adjoins — as — \*\*\*\*\* — a large number are put in order and it is arranged. With these magnets 22 for side attachment walls, a cusp field is stood in a row and formed in a hoop direction in accordance with the inside of the side attachment wall of the processing chamber 2. Consequently, diffusion of the plasma to the inside concerned is prevented.

[0019] Moreover, the thing tabular in an object 9 is assumed with this operation gestalt. The object electrode holder 4 is the member of the shape of a base which lays such an object 9 in a top face, and holds it. RF generator 5 for bias for impressing a self-bias electrical potential difference to an object 9 is formed in the object electrode holder 4. For this RF generator 5 for bias, a thing with a frequency of several MHz to about several 10MHz is used, and it is constituted so that the self-bias electrical potential difference which is a negative in one direction flowed electrical potential difference may be impressed to the front face of an object 9 by the interaction of the plasma and high frequency. Frequency (1.6MHz and about 13.56MHz) of a thing is more specifically suitably usable as RF generator 5 for bias. In addition, for impression of a self-bias electrical potential difference, an object 9 needs to be insulated from a ground in direct current, and, for this reason, a capacitor may be arranged between RF generator 5 for bias, and the object electrode holder 4. In the object electrode holder 4, the temperature control device 41 which controls the temperature of an object 9 to a predetermined value is established, heating or cooling an object 9. And the gas supply system for heat conduction which is not illustrated [ which supplies the thermally conductive good gas of helium etc. between an object 9 and the top face of the object electrode holder 4 ] is established.

[0020] Next, it serves also as explanation of the operation gestalt of invention of the etching approach of the magnetic material of claim 1, and actuation of the equipment of the above-mentioned configuration is explained. First, the front face of an object 9 serves as a magnetic material which consists of nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, an oxide, or the intermetallic compound containing these at least one. Such an object 9 is located in the vacuum auxiliary chamber which is not illustrated [ which is exhausted by the predetermined pressure ]. if it checks that the until [ comparable ] exhaust air of the inside of the processing chamber 2 is carried out by the exhaust air system 21 with the vacuum auxiliary chamber, a non-illustrated gate valve will open, an object 9 will be carried in in the processing chamber 2, and it will be held at the object electrode holder 4. An object 9 is maintained by predetermined temperature according to the temperature control device 41.

[0021] Next, a gas feed system 3 operates and they are CO gas and NH<sub>3</sub>. Gas is introduced in the processing chamber 2 by a predetermined mixing ratio and a predetermined flow rate. The introduced gas is diffused in the dielectric container 11 via the inside of the processing chamber 2. And the source 1 of the plasma operates and the plasma is formed. That is, a RF is supplied to an antenna 12 from RF generator 13 for plasma, and as mentioned above, induction of the helicon wave is carried out. Consequently, the energy of a helicon wave is given to gas and the helicon wave plasma is formed. RF generator 5 for bias is operated to coincidence, and the self-bias electrical potential difference which is a negative in one direction flowed electrical potential difference is given to an object 9.

[0022] The formed plasma is diffused in the processing chamber 2 from the dielectric container 11, and reaches even near the front face of an object 9. Under the present circumstances, the front face of an object 9 is etched by operation of the product in the plasma. After performing predetermined time etching and exhausting the inside of a stop and the processing chamber 2 for actuation of a gas feed system 3, the source 1 of the plasma, and RF generator 5 for bias again, an object 9 is taken out from the processing chamber 2.

[0023] The mechanism of etching in the above-mentioned actuation is explained concretely. CO and NH<sub>3</sub> which were mentioned above The active species of CO is generated in the plasma which consists of mixed gas. this CO active species — nickel of the front face of an object 9, Fe, or Co — reacting — nickel (CO)<sub>4</sub> and Fe (CO)<sub>5</sub> or Co<sub>2</sub> — 8 A carbonyl compound [ like ] arises. On the other hand, from the plasma, ion is pulled out by the front face of the object 9 with which the self-bias electrical potential difference is given, and carries out incidence to it. A surface carbonyl compound evaporates by the impact of this ion incidence.

[0024] Generally transition metals, such as nickel, iron, and cobalt, are difficult for etching at sufficient rate also by reactant etching. That is, since volatility is low (maximum vapor tension is low) or binding energy is large, the chlorides or fluorides of transition metals, such as nickel, iron, and cobalt, cannot be easily etched, even if it produces a chloride and a fluoride using chlorine-based gas or fluorine system gas. In addition, the "binding energy" which made reference here means the thing of the binding energy which works between the molecules of the compound of such transition metals.

[0025] On the other hand, a carbonyl compound is one of a few volatile high (or binding energy is small) compounds also in the compound of these transition metals. As mentioned above, the front face of the magnetic material with which the carbonyl compound was generated by CO active species evaporates by the incidence of the ion in the plasma. According to such a mechanism, etching in the equipment and the approach of this operation gestalt is accomplished. In addition, evaporation of the carbonyl compound in this case also has the what case can be called sputter etching, and is considered [ that it is heated by the energy only given by ion incidence, and may evaporate, and ].

[0026] Moreover, NH<sub>3</sub> mixed by CO gas Gas has the operation which promotes generation of the carbonyl compound by the above-mentioned CO active species. Although CO active species is generated in the plasma as mentioned above, and a carbonyl compound is formed on the surface of a magnetic material of this, as shown in the following formulas (1), in the plasma, the disproportion reaction which CO decomposes into carbon and a

carbon dioxide advances.

$2\text{CO} \rightarrow \text{C} + \text{CO}_2$  .... (1)

Mixed  $\text{NH}_3$  Gas has the work which controls the disproportion reaction of this formula (1). CO active species can be generated to abundance, without losing CO, as a result of controlling disproportion reaction. Thereby, etching of the high rate mentioned above is maintained.

[0027] In the above-mentioned actuation, the source 1 of the plasma forms the helicon wave plasma, and the plasma consistency has become three or more [ $1 \times 10^{11} \text{cm}^{-3}$ ]. This configuration is due to the research result of the artificer who inquired about the relation of the etch rate and plasma consistency in this kind of etching. This point is explained below. Drawing 2 is drawing showing the experimental result investigated about the relation between an etch rate and a plasma consistency. In the experiment shown in this drawing 2, the equipment shown in drawing 1 was used and the nickel-Fe alloy was etched as a magnetic material. The output of RF generator 13 for plasma of the pressure in the processing chamber 2, a quantity of gas flow, and the source 1 of the plasma etc. was adjusted, and the plasma consistency changed it. Moreover, the plasma consistency measured the value in a location with a height of 20mm by the Langmuir probe from the front face of an object 9 on the medial axis of an object 9 in the equipment shown in drawing 1.

[0028] In addition, if a plasma consistency changes, even when the frequency and output of RF generator 5 for bias are the same, the magnitude of a self-bias electrical potential difference will change. Since a self-bias electrical potential difference brings about the electric field for ion incidence, if a self-bias electrical potential difference changes, the strength of the ion bombardment of the front face of an object 9 will also change. In order to investigate purely what kind of effect change of a plasma consistency has on an etch rate, the strength of an ion bombardment must be made regularly. Since it was such, a plasma consistency is changed adjusting the output of RF generator 5 for bias, and it was made to become a fixed self-bias electrical potential difference irrespective of change of a plasma consistency in the experiment shown in this drawing 2.

[0029] The etch rate is rising rapidly bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$  as notably shown in drawing 2. The cause of this point is imagined to be a thing in the condition of the plasma changing bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$ . That is, it is guessed that it is because CO ion with big mass becomes [ many / by leaps and bounds ] bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$ .

[0030] When are explained more concretely and the plasma is formed of the source 1 of the plasma which was mentioned above, all the introduced gas has not plasma-ized (it ionizes into ion and an electron), and the inert gas molecule of a considerable number exists. If energy which the output of RF generator 13 for plasma is raised, and supplies it is made [ many ], the gas to ionize will increase, a plasma consistency will become high, and the part and an inert gas molecule will decrease. Here, it is  $\text{NH}_3$  with ionization energy low while there is little supply energy. Gas ionizes dominantly. And if supply energy increases, it also comes to ionize many high CO gas of ionization energy. CO is  $\text{NH}_3$ . The energy at the time of carrying out an ion bombardment, since mass was large is also  $\text{NH}_3$ . It is high. It is guessed that it is the result of the incidence of CO ion with high mass increasing rapidly that an etch rate rises rapidly bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$ . The equipment and the approach of this operation gestalt are considered as the configuration which etches by forming three or more [ $1 \times 10^{11} \text{cm}^{-3}$ ] high density plasma based on the result of such an experiment. For this reason, compared with the former, an etch rate improves by leaps and bounds, and serves as a practical configuration which can also etch a thick magnetic thin film in a short time.

[0031] In addition, although being attained on the front face of an object 9 is desirable as for 3 more than [ $1 \times 10^{11} \text{cm}^{-3}$  plasma consistency to ] conditions, since it will be in the so-called condition of a sheath between the front face of an object 9, and the plasma, the plasma must have been spread in semantics strict to the front face of an object 9. therefore, 3 more than [ $1 \times 10^{11} \text{cm}^{-3}$  plasma consistency to ] conditions — distance detached building \*\*\*\*\* more than the thickness of the front face of an object 9 to a sheath — \*\* — it will say. In the practical configuration of this kind of equipment, the place of 20mm or more does not usually go into the field of a sheath from the front face of an object 9. Therefore, it is also possible to, set up the conditions 20mm or more of  $1 \times 10^{11} \text{cm}^{-3}$  plasma consistency to more than [ 3 ] by the way from the front face of an object 9. Moreover, about the temperature of the object 9 under etching, it is desirable to consider as 130 degrees C or more. It is because a residue (particulate matter which remained without being etched) will generate after etching termination of predetermined time on the front face of an object 9 if lower than 130 degrees C.

[0032] Next, the plasma etching system which is the operation gestalt of invention of claim 2 and claim 4 is explained. Drawing 3 is the transverse-plane sectional view showing the outline configuration of the plasma etching system which is the operation gestalt of invention of claim 2 and claim 4.

[0033] The equipment shown in this drawing 3 etches by forming the magnetron discharge plasma. When it explains concretely, the equipment shown in drawing 3 is CO and  $\text{NH}_3$  in the source 1 of the plasma which generates the magnetron discharge plasma, the processing chamber 2 which the plasma which the source 1 of the plasma generated diffuses, and the processing chamber 2. It mainly consists of object electrode-holder 4 grades which hold an object 9 in the gas feed system 3 which introduces mixed gas, and the predetermined location in the processing chamber 2. The source 1 of the plasma mainly consists of a magnetron electrode 16 and a power source 17 for discharge which an electrical potential difference is impressed [ power source ] to the magnetron electrode 16, and produces magnetron discharge.

[0034] The magnetron electrode 16 consists of an electrode plate 18 formed so that the object electrode holder 4 might be countered, and a magnet unit 19 prepared behind the electrode plate 18. The magnet unit 19 consists of York 193 which connects the main column-like magnet 191, the circumference magnet 192 of the shape of a

periphery which encloses the main magnet 191, and the main magnet 191 and the circumference magnet 192. In addition, the electrode plate 18 may not be formed but the magnetron electrode 16 may consist of only magnet units 19. An RF generator or negative DC power supply is used for the power source 17 for discharge. Between the main magnet 191 and the circumference magnet 192, the field represented with the line of magnetic force 194 as shown in drawing 3 is set up. This field and the electric field set up according to the power source 17 for discharge cross at right angles, and magnetron structure is attained. The orthogonality relation of a field and electric field is in the condition which stood in a row in the shape of a periphery around the shaft of the magnetron electrode 16.

[0035] When actuation of the equipment shown in drawing 3 is explained, they are CO gas and NH<sub>3</sub> by the gas feed system 3. The source 1 of the plasma is operated introducing gas in the processing chamber 2 by a predetermined mixing ratio and a predetermined flow rate. That is, a predetermined electrical potential difference is impressed to the electrode plate 18 according to the power source 17 for discharge. Consequently, discharge arises in the introduced gas. Under the present circumstances, an electron carries out magnetron movement, is efficient and makes an inert gas molecule ionize by the orthogonality relation of a field and electric field. Of this discharge, gas plasma-izes and the magnetron discharge plasma is formed. And a carbonyl compound is formed in the front face of an object 9 the same with having mentioned above of CO active species generated in the plasma, and this carbonyl compound evaporates by the ion bombardment. Under the present circumstances, a self-bias electrical potential difference is given to an object 9 by RF generator 5 for bias, and ion carries out incidence to a front face efficiently.

[0036] Also in this second operation gestalt, a plasma consistency is three or more [ $1 \times 10^{11} \text{ cm}^{-3}$ ], and in order that CO ion with big mass may carry out many incidence, compared with the former, a high etch rate is obtained by leaps and bounds. Since the source 1 of the plasma mentioned above carries out magnetron movement of the electron, it can form the plasma of such high density easily.

[0037]

[Example] Next, the example of the etching approach of the above-mentioned operation gestalt is explained. First, the nickel-Fe alloy thin film was created by sputtering on the silicon wafer, and the thing in which the mask pattern made from titanium was formed on this was used as an object 9. The thing of the first operation gestalt was used as equipment. The object 9 was held on the object electrode holder 4, and the temperature was maintained at 150 degrees C. And it is CO gas by the gas feed system 3 20SCCM(s) (SCCM is the flow rate (cubic centimeter) of the gas in 0-degree-C one atmospheric pressure), and NH<sub>3</sub> Gas was introduced in the processing chamber 2 by the flow rate of 20SCCM(s). Moreover, the inside of the processing chamber 2 was maintained to 0.8Pa by the exhaust air system 21. In this condition, by RF generator 13 for plasma, the high frequency of 13.56MHz1500W was supplied and it etched by forming the plasma of the consistency of  $1 \times 10^{11} \text{ cm}^{-3}$ . Consequently, the nickel-Fe alloy thin film was etched at the very high rate of about 80nm/minute. Moreover, the etch rate of the titanium which is a mask is about [ of the etch rate of a nickel-Fe alloy ] 1/9, and the result of having excelled also in respect of selectivity was obtained. After etching, even if it left it for two weeks under atmospheric air of 40% of humidity, the after corrosion was not generated.

[0038] Moreover, as another object 9, the FeN thin film was created by sputtering on the silicon wafer, and the thing in which the mask pattern made from titanium was formed on this was used. As equipment, the thing of the first operation gestalt was used similarly. It is the flow rate of 170 degrees C and CO gas about the temperature of this object 9 35SCCM(s) and NH<sub>3</sub> The pressure in 50SCCM(s) and the processing chamber 2 was set to 0.4Pa for the flow rate of gas, and it etched by the high frequency of 13.56MHz3000W by forming the helicon wave plasma of about [ $5 \times 10^{11} \text{ cm}^{-3}$ ] three consistency. Consequently, the FeN alloy was etched at a very high rate called a part for 130nm/.

[0039] Furthermore, as another object 9, the nickel-Fe-Co alloy thin film was created by sputtering on the silicon wafer, and the thing in which the mask pattern made from titanium was formed on this was used. The thing of the second operation gestalt was used as equipment. It is the flow rate of 150 degrees C and CO gas about the temperature of this object 9 20SCCM(s) and NH<sub>3</sub> The pressure in 70SCCM(s) and the processing chamber 2 was set to 2.6Pa for the flow rate of gas, and it etched by the RF of 13.56MH800W by forming the magnetron discharge plasma of about [ $2 \times 10^{11} \text{ cm}^{-3}$ ] three consistency. Consequently, the nickel-Fe-Co alloy was etched at a very high rate called a part for 90nm/.

[0040] The magnetic material etched in the invention in this application is not limited to what was mentioned above that what is necessary is just nickel, Fe, Co, the alloy that contains at least one among these, a nitride, an oxide, or an intermetallic compound containing these one. For example, it can constitute so that magnetic materials, such as the Sendust alloy (Fe-aluminum-Si alloy), an amorphous alloy, and a granular alloy (Co-aluminum-O alloy), may be etched.

[0041] Moreover, if the plasma of three or more [ $1 \times 10^{11} \text{ cm}^{-3}$ ] consistencies can be formed even if it is except what forms the helicon wave plasma mentioned above, or the thing which forms the magnetron discharge plasma, the thing of other configurations can also be used for the source 1 of the plasma. For example, the ECR (electron cyclotron resonance) plasma is formed. Furthermore, as an application of an etching process, a micro transformer besides manufacture of the thin film magnetic head, manufacture of a micro magnetic circuit, etc. which were mentioned above are mentioned.

[0042]

[Effect of the Invention] According to the approach or equipment of each claim of this application, compared with the former, an etch rate improves by leaps and bounds, and serves as a practical configuration which can

also etch a thick magnetic thin film in a short time as explained above.

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[Translation done.]



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**TECHNICAL FIELD**

[Field of the Invention] This invention relates to the etching technique used suitable for especially manufacture of the thin film magnetic head about the etching technique of a magnetic material.

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#### PRIOR ART

[Description of the Prior Art] The technique which etches a magnetic material is an important technique in manufacture of the thin film magnetic head carried in a magnetic disk drive etc. Many frame plating is used in manufacture of the thin film magnetic head. Drawing 4 is drawing explaining frame plating as a conventional technique. First, the frame resist 901 is formed in the front face of a substrate 90 by the predetermined pattern ( drawing 4 (1)), and a magnetic thin film 902 is formed by plating to the frame resist 901. ( Drawing 4 (2)) . And as the magnetic thin film 902 inside the frame resist 901 is covered, the up resist 903 is formed ( drawing 4 (3)). Wet etching is carried out with an etching reagent in this condition, the magnetic thin film 902 of the outside of the frame resist 901 is removed, and that Gokami section resist 903 and the frame resist 901 are exfoliated. Consequently, the magnetic thin film 902 of a predetermined pattern is obtained ( drawing 4 (4)).

[0003] To such frame plating, the limitation is pointed out by making detailed-ization of the thin film magnetic head accompanying the densification of a magnetic disk into a background. Although a thick frame resist needs to be formed of frame plating, it is because the formation becomes difficult by the detailed pattern.

[0004] Etching a magnetic thin film directly by the dry etching method, and obtaining the magnetic thin film of a predetermined pattern is examined under such circumstances. One approach is the approach of making carry out incidence of the ion to a magnetic thin film, and etching it into it. For example, incidence of the ion can be carried out from the plasma of argon gas, or it is possible to irradiate the ion beam of an argon and to etch it. However, such an approach is physical etching and is bad. [ of the selectivity over other ingredients, such as a substrate and a mask, ] Moreover, generally an etch rate is also low and has a problem in respect of productivity.

[0005] Then, applying reactive ion etching (ReactiveIon Etching, RIE) to etching of this kind of magnetic material is examined as chemical etching. Etching of the magnetic material by RIE is reported by J.Vac.Sci.Technol.A4 (4), 1841 (1986), and Appl.Phys.Lett.67(21) and 3194 (1995), for example. However, in these reports, an etch rate is as low as the following by 10nm/.

[0006] Recent years come and the example from which a part for etch rate/of 300nm of a nickel-Fe alloy was obtained is reported by by using chlorine gas for Appl.Phys.Lett.71(9) 1255 (1997) etc. However, by etching of the magnetic material by chlorine gas, the problem of the corrosion by chlorine remaining to an after corrosion, i.e., a front face, tends to occur. Although an after corrosion can be prevented by processing washing with water after etching etc., it has the problem on which a routing counter increases.

[0007] The approach indicated by the patent No. 2677321 official report is one of those use neither the chlorine leading to an after corrosion, nor a fluorine. In this official report, it is supposed by using the gas which mixed ammonia (NH3) with the carbon monoxide (CO) that a part for etch rate/of 24.4nm of a part for /and the etch rate Co-Cr alloy of 35nm of a nickel-Fe alloy was obtained, respectively.

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EFFECT OF THE INVENTION

[Effect of the Invention] According to the approach or equipment of each claim of this application, compared with the former, an etch rate improves by leaps and bounds, and serves as a practical configuration which can also etch a thick magnetic thin film in a short time as explained above.

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**TECHNICAL PROBLEM**

[Problem(s) to be Solved by the Invention] As mentioned above, it is CO and NH<sub>3</sub>. It is possible to etch the magnetic thin film which consists of nickel suitable for the thin film magnetic head etc., Co, or Fe, without causing the problem of an after corrosion by using mixed gas. However, the etch rate is about 24-35nm/minute, and is still low. It is necessary to etch thickness of no less than 2 micrometers in manufacture of the thin film magnetic head. Therefore, the present etch rate will take the time amount for about 50 - 80 minutes, and it is count still far from utilization. This invention is accomplished in consideration of such a situation, makes it possible to etch at the high rate far exceeding the present condition in etching of the magnetic thin film using the mixed gas of CO and NH<sub>3</sub>, and has technical meaning of opening the way of utilization of this kind to manufacture of the thin film magnetic head etc. of technique.

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## MEANS

[Means for Solving the Problem] In order to solve the above-mentioned technical problem, invention of this application according to claim 1 forms the plasma of the mixed gas of ammonia and a carbon monoxide in the space which overlooks the front face of the object which is the magnetic material which consists of nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, an oxide, or the intermetallic compound containing these at least one by three or more [ 1x10<sup>11</sup>cm<sup>-3</sup> ] consistencies, and has the configuration of etching the front face which is said magnetic material. In order to solve the above-mentioned technical problem, moreover, invention according to claim 2 The processing chamber equipped with the exhaust air system, and the gas feed system which mixes and introduces ammonia gas and carbon monoxide gas in a processing chamber, The source of the plasma which supplies energy to the introduced gas and forms the plasma of these gas by three or more [ 1x10<sup>11</sup>cm<sup>-3</sup> ] consistencies, A front face Nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, or an oxide, Or it has the configuration of having the object electrode holder which holds the object which is the magnetic material which consists of the intermetallic compound containing these at least one in the location where the front face is etched by said plasma. Moreover, in order to solve the above-mentioned technical problem, invention according to claim 3 has the configuration that said source of the plasma is what forms the helicon wave plasma, in the configuration of above-mentioned claim 2. Moreover, in order to solve the above-mentioned technical problem, invention according to claim 4 has the configuration that said source of the plasma is what forms the magnetron discharge plasma, in the configuration of above-mentioned claim 2.

[0010]

[Embodiment of the Invention] Hereafter, the gestalt of operation of the invention in this application is explained. First, the operation gestalt of invention of claim 2 and claim 3 is explained. Drawing 1 is the transverse-plane sectional view showing the outline configuration of the plasma etching system which is the operation gestalt of invention of claim 2 and claim 3.

[0011] The plasma etching system shown in drawing 1 is equipment which etches the front face of an object by the helicon wave plasma. The helicon wave plasma attracts attention as what can form the plasma of high density also by the comparatively low pressure. Although the mechanism of the energy transfer in the helicon wave plasma has the place which is not sufficiently clear, it is thought that the plasma is formed by kinetic energy being given to an electron from a RF according to the phenomenon called Landau damping. That is, since it is the same as it saw from the electron and the helicon wave has stopped when the rate of the electron which moves while rotating by the field is equal to the phase velocity of a helicon wave, it is continuously accelerated from a helicon wave, an electron absorbs energy, and the plasma of high density is formed of this.

[0012] When the configuration of equipment is explained concretely, the equipment shown in drawing 1 is CO and NH<sub>3</sub> in the source 1 of the plasma which generates the helicon wave plasma, the processing chamber 2 which the plasma which the source 1 of the plasma generated diffuses, and the processing chamber 2. It mainly consists of object electrode-holder 4 grades which hold the object 9 of etching in the gas feed system 3 which introduces mixed gas, and the predetermined location in the processing chamber 2.

[0013] The source 1 of the plasma consists of RF generator 13 for plasma which generates the high-frequency power supplied at the antenna 12 which carries out induction of the helicon wave, and an antenna 12 in the dielectric container 11 airtightly connected as the building envelope was open for free passage to the processing chamber 2, and the dielectric container 11, and magnet 14 grade which sets up a predetermined field in the dielectric container 11. An end is opening, and the dielectric container 11 is the member of the shape of a cylinder which the other end has closed in the shape of a semi-sphere, and is formed with the quartz etc. Opening is prepared in the upper wall section of the processing chamber 2, and as opening of the end of the dielectric container 11 and opening of this upper wall section are made to open for free passage, the dielectric container 11 is airtightly connected to the processing chamber 2.

[0014] The thing which RF generator 13 for plasma makes generate a 13.56MHz RF is used. An antenna 12 is the configuration almost in a circle which the cylindrical or band-like member was rounded off [ configuration ], and made a little both ends estrange, and it is arranged on the dielectric container 11 and the same axle so that the dielectric container 11 may be surrounded. The antenna 12 is formed in two shaft orientations of the dielectric container 11, and both both ends are electrically connected with the junction rod 121, respectively.

[0015] The high periphery power source 13 for plasma and the antenna 12 are connected through the non-illustrated adjustment machine by transmission line 15 like a coaxial cable. When the RF which RF generator 13 for plasma generated is supplied to two antennas 12 by the transmission line 15, at two antennas 12, the current of the reverse sense flows mutually. Consequently, induction of the helicon wave (circularly-polarized wave of

the right-handed rotation same here as a whistler wave) is carried out to the interior of the dielectric container 11. in addition, alienation of two antennas 12 — spacing is selected so that the phase velocity of a helicon wave may become the optimal in relation with electronic passing speed.

[0016] Moreover, a magnet 14 is for setting up a field parallel to the travelling direction of a helicon wave in the dielectric container 11. Magnetic field strength is made into about 100 gauss near the medial axis of the dielectric container 11. With this operation gestalt, a magnet 14 is an electromagnet and is formed on [ two ] the same axle. The outside magnet 14 is mainly formed for the inside magnet 14 for adjustment of a field configuration for helicon wave plasma formation.

[0017] A gas feed system 3 is the bomb 31 which accumulated CO gas, and NH<sub>3</sub>. It mainly consists of a bulb 33 prepared on the piping 32 which connects the bomb 31 which accumulated gas, each bomb 31, and the processing chamber 2, a flow regulator 34, a non-illustrated filter, etc. CO gas and NH<sub>3</sub> Each flow regulator 34 can adjust now the mixing ratio and flow rate of gas. The processing chamber 2 is the airtight vacuum housing equipped with the non-illustrated gate valve. The exhaust air system 21 attached to the processing chamber 2 is equipped with a diffusion pump, a turbo molecular pump, etc., and is constituted possible [ exhaust air of the inside of the processing chamber 2 ] to the predetermined ultimate-pressure force.

[0018] As shown in drawing 1, many magnets 22 for side attachment walls are formed in the outside of the side attachment wall of the processing chamber 2. the magnets 22 for side attachment walls differ mutually with the magnets which the magnetic pole of Men who faces the side attachment wall of the processing chamber 2 adjoins — as — \*\*\*\*\* — a large number are put in order and it is arranged. With these magnets 22 for side attachment walls, a cusp field is stood in a row and formed in a hoop direction in accordance with the inside of the side attachment wall of the processing chamber 2. Consequently, diffusion of the plasma to the inside concerned is prevented.

[0019] Moreover, the thing tabular in an object 9 is assumed with this operation gestalt. The object electrode holder 4 is the member of the shape of a base which lays such an object 9 in a top face, and holds it. RF generator 5 for bias for impressing a self-bias electrical potential difference to an object 9 is formed in the object electrode holder 4. For this RF generator 5 for bias, a thing with a frequency of several MHz to about several 10MHz is used, and it is constituted so that the self-bias electrical potential difference which is a negative in one direction flowed electrical potential difference may be impressed to the front face of an object 9 by the interaction of the plasma and high frequency. Frequency (1.6MHz and about 13.56MHz) of a thing is more specifically suitably usable as RF generator 5 for bias. In addition, for impression of a self-bias electrical potential difference, an object 9 needs to be insulated from a ground in direct current, and, for this reason, a capacitor may be arranged between RF generator 5 for bias, and the object electrode holder 4. In the object electrode holder 4, the temperature control device 41 which controls the temperature of an object 9 to a predetermined value is established, heating or cooling an object 9. And the gas supply system for heat conduction which is not illustrated [ which supplies the thermally conductive good gas of helium etc. between an object 9 and the top face of the object electrode holder 4 ] is established.

[0020] Next, it serves also as explanation of the operation gestalt of invention of the etching approach of the magnetic material of claim 1, and actuation of the equipment of the above-mentioned configuration is explained. First, the front face of an object 9 serves as a magnetic material which consists of nickel, iron, cobalt, the alloy that contains at least one among these, a nitride, an oxide, or the intermetallic compound containing these at least one. Such an object 9 is located in the vacuum auxiliary chamber which is not illustrated [ which is exhausted by the predetermined pressure ]. if it checks that the until [ comparable ] exhaust air of the inside of the processing chamber 2 is carried out by the exhaust air system 21 with the vacuum auxiliary chamber, a non-illustrated gate valve will open, an object 9 will be carried in in the processing chamber 2, and it will be held at the object electrode holder 4. An object 9 is maintained by predetermined temperature according to the temperature control device 41.

[0021] Next, a gas feed system 3 operates and they are CO gas and NH<sub>3</sub>. Gas is introduced in the processing chamber 2 by a predetermined mixing ratio and a predetermined flow rate. The introduced gas is diffused in the dielectric container 11 via the inside of the processing chamber 2. And the source 1 of the plasma operates and the plasma is formed. That is, a RF is supplied to an antenna 12 from RF generator 13 for plasma, and as mentioned above, induction of the helicon wave is carried out. Consequently, the energy of a helicon wave is given to gas and the helicon wave plasma is formed. RF generator 5 for bias is operated to coincidence, and the self-bias electrical potential difference which is a negative in one direction flowed electrical potential difference is given to an object 9.

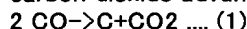
[0022] The formed plasma is diffused in the processing chamber 2 from the dielectric container 11, and reaches even near the front face of an object 9. Under the present circumstances, the front face of an object 9 is etched by operation of the product in the plasma. After performing predetermined time etching and exhausting the inside of a stop and the processing chamber 2 for actuation of a gas feed system 3, the source 1 of the plasma, and RF generator 5 for bias again, an object 9 is taken out from the processing chamber 2.

[0023] The mechanism of etching in the above-mentioned actuation is explained concretely. CO and NH<sub>3</sub> which were mentioned above The active species of CO is generated in the plasma which consists of mixed gas. this CO active species — nickel of the front face of an object 9, Fe, or Co — reacting — nickel (CO)<sub>4</sub> and Fe (CO)<sub>5</sub> or Co<sub>2</sub> — 8 A carbonyl compound [ like ] arises. On the other hand, from the plasma, ion is pulled out by the front face of the object 9 with which the self-bias electrical potential difference is given, and carries out incidence to it. A surface carbonyl compound evaporates by the impact of this ion incidence.

[0024] Generally transition metals, such as nickel, iron, and cobalt, are difficult for etching at sufficient rate also by reactant etching. That is, since volatility is low (maximum vapor tension is low) or binding energy is large, the chlorides or fluorides of transition metals, such as nickel, iron, and cobalt, cannot be easily etched, even if it produces a chloride and a fluoride using chlorine-based gas or fluorine system gas. In addition, the "binding energy" which made reference here means the thing of the binding energy which works between the molecules of the compound of such transition metals.

[0025] On the other hand, a carbonyl compound is one of a few volatile high (or binding energy is small) compounds also in the compound of these transition metals. As mentioned above, the front face of the magnetic material with which the carbonyl compound was generated by CO active species evaporates by the incidence of the ion in the plasma. According to such a mechanism, etching in the equipment and the approach of this operation gestalt is accomplished. In addition, evaporation of the carbonyl compound in this case also has the what case can be called sputter etching, and is considered [ that it is heated by the energy only given by ion incidence, and may evaporate, and ].

[0026] Moreover, NH<sub>3</sub> mixed by CO gas Gas has the operation which promotes generation of the carbonyl compound by the above-mentioned CO active species. Although CO active species is generated in the plasma as mentioned above, and a carbonyl compound is formed on the surface of a magnetic material of this, as shown in the following formulas (1), in the plasma, the disproportion reaction which CO decomposes into carbon and a carbon dioxide advances.



Mixed NH<sub>3</sub> Gas has the work which controls the disproportion reaction of this formula (1). CO active species can be generated to abundance, without losing CO, as a result of controlling disproportion reaction. Thereby, etching of the high rate mentioned above is maintained.

[0027] In the above-mentioned actuation, the source 1 of the plasma forms the helicon wave plasma, and the plasma consistency has become three or more [  $1 \times 10^{11} \text{cm}^{-3}$  ]. This configuration is due to the research result of the artificer who inquired about the relation of the etch rate and plasma consistency in this kind of etching. This point is explained below. Drawing 2 is drawing showing the experimental result investigated about the relation between an etch rate and a plasma consistency. In the experiment shown in this drawing 2, the equipment shown in drawing 1 was used and the nickel-Fe alloy was etched as a magnetic material. The output of RF generator 13 for plasma of the pressure in the processing chamber 2, a quantity of gas flow, and the source 1 of the plasma etc. was adjusted, and the plasma consistency changed it. Moreover, the plasma consistency measured the value in a location with a height of 20mm by the Langmuir probe from the front face of an object 9 on the medial axis of an object 9 in the equipment shown in drawing 1.

[0028] in addition, if a plasma consistency changes, even when the frequency and output of RF generator 5 for bias are the same, the magnitude of a self-bias electrical potential difference will change. Since a self-bias electrical potential difference brings about the electric field for ion incidence, if a self-bias electrical potential difference changes, the strength of the ion bombardment of the front face of an object 9 will also change. In order to investigate purely what kind of effect change of a plasma consistency has on an etch rate, the strength of an ion bombardment must be made regularity. Since it was such, a plasma consistency is changed adjusting the output of RF generator 5 for bias, and it was made to become a fixed self-bias electrical potential difference irrespective of change of a plasma consistency in the experiment shown in this drawing 2.

[0029] The etch rate is rising rapidly bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$  as notably shown in drawing 2. The cause of this point is imagined to be a thing in the condition of the plasma changing bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$ . That is, it is guessed that it is because CO ion with big mass becomes [ many / by leaps and bounds ] bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$ .

[0030] When are explained more concretely and the plasma is formed of the source 1 of the plasma which was mentioned above, all the introduced gas has not plasma-ized (it ionizes into ion and an electron), and the inert gas molecule of a considerable number exists. If energy which the output of RF generator 13 for plasma is raised, and supplies it is made [ many ], the gas to ionize will increase, a plasma consistency will become high, and the part and an inert gas molecule will decrease. Here, it is NH<sub>3</sub> with ionization energy low while there is little supply energy. Gas ionizes dominantly. And if supply energy increases, it also comes to ionize many high CO gas of ionization energy. CO is NH<sub>3</sub>. The energy at the time of carrying out an ion bombardment, since mass was large is also NH<sub>3</sub>. It is high. It is guessed that it is the result of the incidence of CO ion with high mass increasing rapidly that an etch rate rises rapidly bordering on plasma consistency  $1 \times 10^{11} \text{cm}^{-3}$ . The equipment and the approach of this operation gestalt are considered as the configuration which etches by forming three or more [  $1 \times 10^{11} \text{cm}^{-3}$  ] high density plasma based on the result of such an experiment. For this reason, compared with the former, an etch rate improves by leaps and bounds, and serves as a practical configuration which can also etch a thick magnetic thin film in a short time.

[0031] In addition, although being attained on the front face of an object 9 is desirable as for 3 more than [  $1 \times 10^{11} \text{cm}^{-3}$  plasma consistency to ] conditions, since it will be in the so-called condition of a sheath between the front face of an object 9, and the plasma, the plasma must have been spread in semantics strict to the front face of an object 9. therefore, 3 more than [  $1 \times 10^{11} \text{cm}^{-3}$  plasma consistency to ] conditions — distance detached building \*\*\*\*\* more than the thickness of the front face of an object 9 to a sheath — \*\* — it will say. In the practical configuration of this kind of equipment, the place of 20mm or more does not usually go into the field of a sheath from the front face of an object 9. Therefore, it is also possible to, set up the conditions 20mm or more of  $1 \times 10^{11} \text{cm}^{-3}$  plasma consistency to more than [ 3 ] by the way from the front face of an object 9. Moreover,



about the temperature of the object 9 under etching, it is desirable to consider as 130 degrees C or more. It is because a residue (particulate matter which remained without being etched) will generate after etching termination of predetermined time on the front face of an object 9 if lower than 130 degrees C.

[0032] Next, the plasma etching system which is the operation gestalt of invention of claim 2 and claim 4 is explained. Drawing 3 is the transverse-plane sectional view showing the outline configuration of the plasma etching system which is the operation gestalt of invention of claim 2 and claim 4.

[0033] The equipment shown in this drawing 3 etches by forming the magnetron discharge plasma. When it explains concretely, the equipment shown in drawing 3 is CO and NH<sub>3</sub> in the source 1 of the plasma which generates the magnetron discharge plasma, the processing chamber 2 which the plasma which the source 1 of the plasma generated diffuses, and the processing chamber 2. It mainly consists of object electrode-holder 4 grades which hold an object 9 in the gas feed system 3 which introduces mixed gas, and the predetermined location in the processing chamber 2. The source 1 of the plasma mainly consists of a magnetron electrode 16 and a power source 17 for discharge which an electrical potential difference is impressed [ power source ] to the magnetron electrode 16, and produces magnetron discharge.

[0034] The magnetron electrode 16 consists of an electrode plate 18 formed so that the object electrode holder 4 might be countered, and a magnet unit 19 prepared behind the electrode plate 18. The magnet unit 19 consists of York 193 which connects the main column-like magnet 191, the circumference magnet 192 of the shape of a periphery which encloses the main magnet 191, and the main magnet 191 and the circumference magnet 192. In addition, the electrode plate 18 may not be formed but the magnetron electrode 16 may consist of only magnet units 19. An RF generator or negative DC power supply is used for the power source 17 for discharge. Between the main magnet 191 and the circumference magnet 192, the field represented with the line of magnetic force 194 as shown in drawing 3 is set up. This field and the electric field set up according to the power source 17 for discharge cross at right angles, and magnetron structure is attained. The orthogonality relation of a field and electric field is in the condition which stood in a row in the shape of a periphery around the shaft of the magnetron electrode 16.

[0035] When actuation of the equipment shown in drawing 3 is explained, they are CO gas and NH<sub>3</sub> by the gas feed system 3. The source 1 of the plasma is operated introducing gas in the processing chamber 2 by a predetermined mixing ratio and a predetermined flow rate. That is, a predetermined electrical potential difference is impressed to the electrode plate 18 according to the power source 17 for discharge. Consequently, discharge arises in the introduced gas. Under the present circumstances, an electron carries out magnetron movement, is efficient and makes an inert gas molecule ionize by the orthogonality relation of a field and electric field. Of this discharge, gas plasma-izes and the magnetron discharge plasma is formed. And a carbonyl compound is formed in the front face of an object 9 the same with having mentioned above of CO active species generated in the plasma, and this carbonyl compound evaporates by the ion bombardment. Under the present circumstances, a self-bias electrical potential difference is given to an object 9 by RF generator 5 for bias, and ion carries out incidence to a front face efficiently.

[0036] Also in this second operation gestalt, a plasma consistency is three or more [  $1 \times 10^{11} \text{ cm}^{-3}$  ], and in order that CO ion with big mass may carry out many incidence, compared with the former, a high etch rate is obtained by leaps and bounds. Since the source 1 of the plasma mentioned above carries out magnetron movement of the electron, it can form the plasma of such high density easily.

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**EXAMPLE**

[Example] Next, the example of the etching approach of the above-mentioned operation gestalt is explained. First, the nickel-Fe alloy thin film was created by sputtering on the silicon wafer, and the thing in which the mask pattern made from titanium was formed on this was used as an object 9. The thing of the first operation gestalt was used as equipment. The object 9 was held on the object electrode holder 4, and the temperature was maintained at 150 degrees C. And it is CO gas by the gas feed system 3 20SCCM(s) (SCCM is the flow rate (cubic centimeter) of the gas in 0-degree-C one atmospheric pressure), and NH3 Gas was introduced in the processing chamber 2 by the flow rate of 20SCCM(s). Moreover, the inside of the processing chamber 2 was maintained to 0.8Pa by the exhaust air system 21. In this condition, by RF generator 13 for plasma, the high frequency of 13.56MHz1500W was supplied and it etched by forming the plasma of the consistency of  $1 \times 10^{11} \text{cm}^{-3}$ . Consequently, the nickel-Fe alloy thin film was etched at the very high rate of about 80nm/minute. Moreover, the etch rate of the titanium which is a mask is about [ of the etch rate of a nickel-Fe alloy ] 1/9, and the result of having excelled also in respect of selectivity was obtained. After etching, even if it left it for two weeks under atmospheric air of 40% of humidity, the after corrosion was not generated.

[0038] Moreover, as another object 9, the FeN thin film was created by sputtering on the silicon wafer, and the thing in which the mask pattern made from titanium was formed on this was used. As equipment, the thing of the first operation gestalt was used similarly. It is the flow rate of 170 degrees C and CO gas about the temperature of this object 9 35SCCM(s) and NH3 The pressure in 50SCCM(s) and the processing chamber 2 was set to 0.4Pa for the flow rate of gas, and it etched by the high frequency of 13.56MHz3000W by forming the helicon wave plasma of about [  $5 \times 10^{11} \text{cm}^{-3}$  ] three consistency. Consequently, the FeN alloy was etched at a very high rate called a part for 130nm/.

[0039] Furthermore, as another object 9, the nickel-Fe-Co alloy thin film was created by sputtering on the silicon wafer, and the thing in which the mask pattern made from titanium was formed on this was used. The thing of the second operation gestalt was used as equipment. It is the flow rate of 150 degrees C and CO gas about the temperature of this object 9 20SCCM(s) and NH3 The pressure in 70SCCM(s) and the processing chamber 2 was set to 2.6Pa for the flow rate of gas, and it etched by the RF of 13.56MH800W by forming the magnetron discharge plasma of about [  $2 \times 10^{11} \text{cm}^{-3}$  ] three consistency. Consequently, the nickel-Fe-Co alloy was etched at a very high rate called a part for 90nm/.

[0040] The magnetic material etched in the invention in this application is not limited to what was mentioned above that what is necessary is just nickel, Fe, Co, the alloy that contains at least one among these, a nitride, an oxide, or an intermetallic compound containing these one. For example, it can constitute so that magnetic materials, such as the Sendust alloy (Fe-aluminum-Si alloy), an amorphous alloy, and a granular alloy (Co-aluminum-O alloy), may be etched.

[0041] Moreover, if the plasma of three or more [  $1 \times 10^{11} \text{cm}^{-3}$  ] consistencies can be formed even if it is except what forms the helicon wave plasma mentioned above, or the thing which forms the magnetron discharge plasma, the thing of other configurations can also be used for the source 1 of the plasma. For example, the ECR (electron cyclotron resonance) plasma is formed. Furthermore, as an application of an etching process, a micro transformer besides manufacture of the thin film magnetic head, manufacture of a micro magnetic circuit, etc. which were mentioned above are mentioned.

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[Translation done.]

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DESCRIPTION OF DRAWINGS

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[Brief Description of the Drawings]

[Drawing 1] It is the transverse-plane sectional view showing the outline configuration of the plasma etching system which is the operation gestalt of invention of claim 2 and claim 3.

[Drawing 2] It is drawing showing the experimental result investigated about the relation between an etch rate and a plasma consistency.

[Drawing 3] It is the transverse-plane sectional view showing the outline configuration of the plasma etching system which is the operation gestalt of invention of claim 2 and claim 4.

[Drawing 4] It is drawing explaining frame plating as a conventional technique.

[Description of Notations]

- 1 Source of Plasma
- 2 Processing Chamber
- 3 Gas Feed System
- 4 Object Electrode Holder
- 5 RF Generator for Bias
- 9 Object

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[Translation done.]

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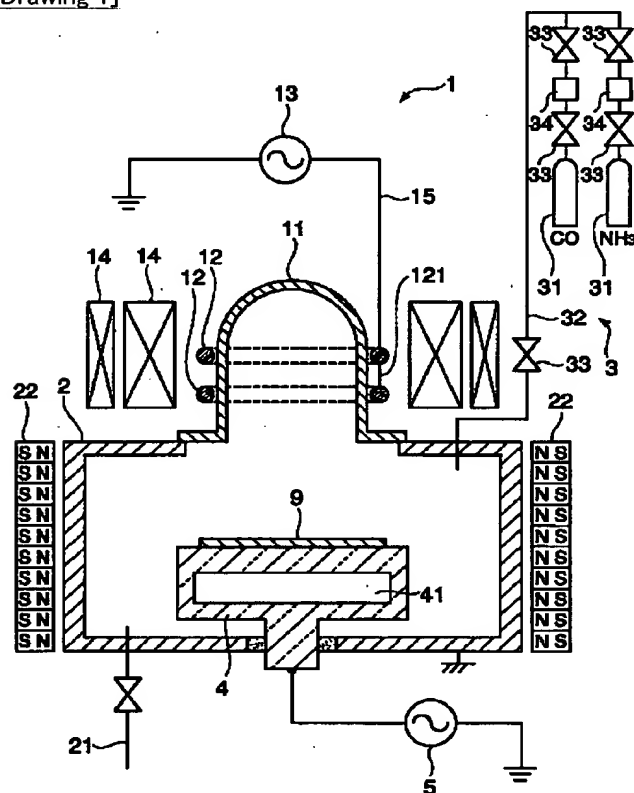
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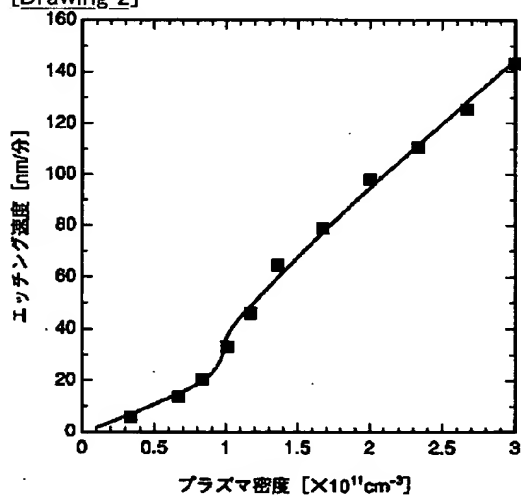
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## DRAWINGS

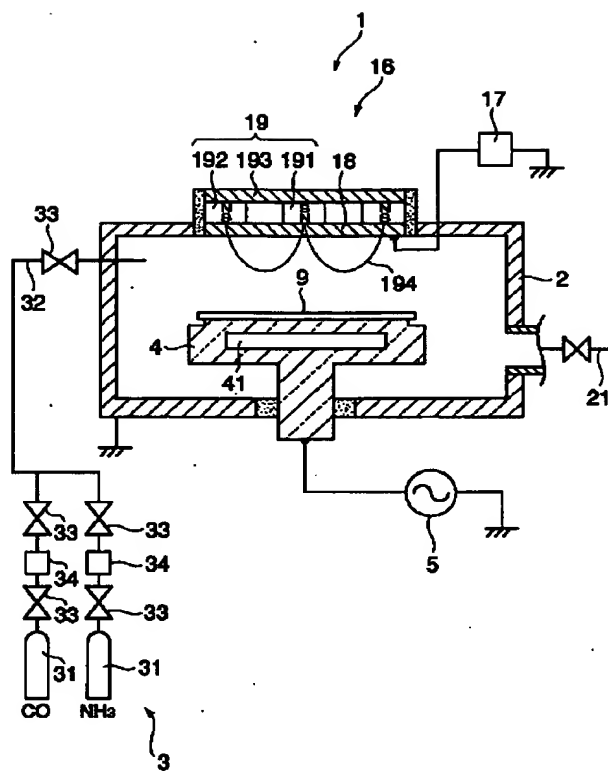
[Drawing 1]



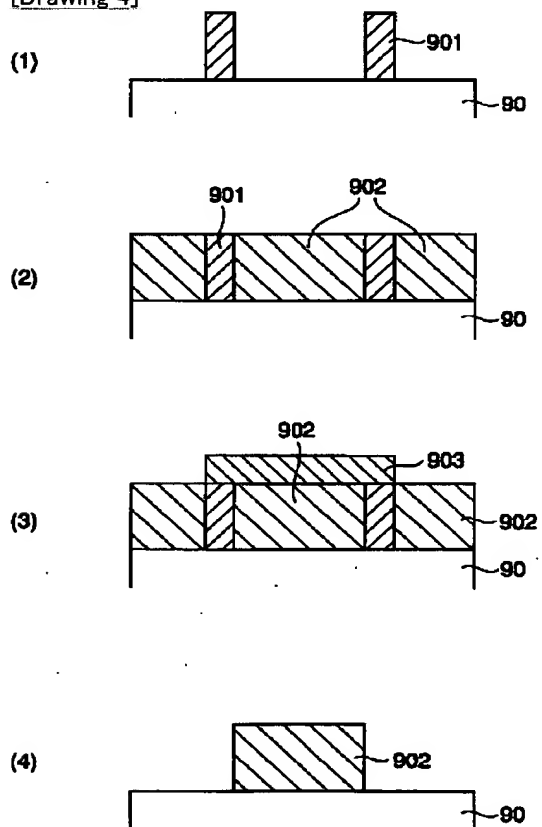
[Drawing 2]



[Drawing 3]



[Drawing 4]



[Translation done.]

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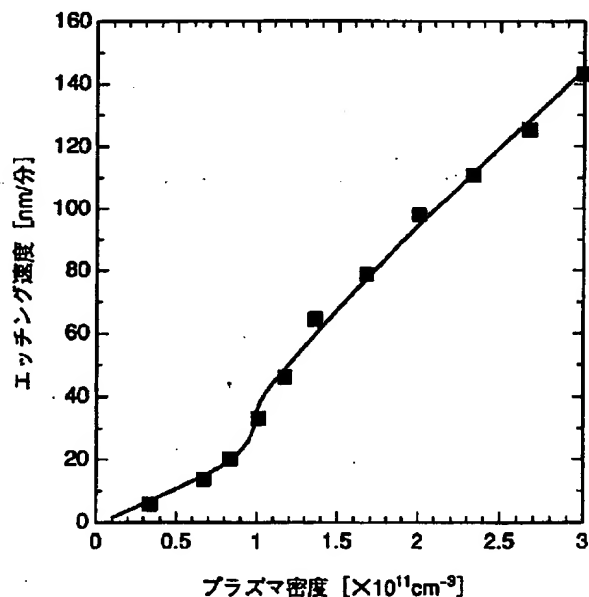
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(54) 【発明の名称】 磁性材料のエッチング方法及びプラズマエッチング装置

(57) 【要約】

【課題】 一酸化炭素とアンモニアの混合ガスを用いた磁性薄膜のエッチングの速度を遥かに高い速度とし、薄膜磁気ヘッド等の製造へのこの種の技術の実用化の途を開く。

【解決手段】 処理チャンバー2内にガス導入系3によって一酸化炭素とアンモニアの混合ガスが導入され、ヘリコン波プラズマを形成するプラズマ源1によってこれらのガスのプラズマが形成される。ニッケル、鉄、コバルト、これらのうち少なくとも一つを含む合金、窒化物もしくは酸化物、又は、これらの少なくとも一つを含む金属間化合物から成る磁性材料である対象物9の表面には、一酸化炭素との反応によりカルボニル化合物が生成され、このカルボニル化合物が蒸発してエッチングが行われる。プラズマは $1 \times 10^{11} \text{ cm}^{-3}$ 以上の密度となっており、質量の大きな一酸化炭素ガスが多くイオン化していて対象物9の表面に多く入射するため、エッチング速度が高くなる。



## 【特許請求の範囲】

【請求項 1】 ニッケル、鉄、コバルト、これらのうち少なくとも一つを含む合金、窒化物もしくは酸化物、又は、これらの少なくとも一つを含む金属間化合物から成る磁性材料である対象物の表面を臨む空間に、アンモニア及び一酸化炭素の混合ガスのプラズマを  $1 \times 10^{11} \text{ cm}^{-3}$  以上の密度で形成して、前記磁性材料である表面をエッチングすることを特徴とする磁性材料のエッチング方法。

【請求項 2】 排気系を備えた処理チャンバーと、処理チャンバー内にアンモニアガス及び一酸化炭素ガスを混合して導入するガス導入系と、導入されたガスにエネルギーを供給してこれらのガスのプラズマを  $1 \times 10^{11} \text{ cm}^{-3}$  以上の密度で形成するプラズマ源と、表面がニッケル、鉄、コバルト、これらのうち少なくとも一つを含む合金、窒化物もしくは酸化物、又は、これらの少なくとも一つを含む金属間化合物から成る磁性材料である対象物をその表面が前記プラズマによってエッチングされる位置に保持する対象物ホルダーとを備えていることを特徴とするプラズマエッチング装置。

【請求項 3】 前記プラズマ源は、ヘリコン波プラズマを形成するものであることを特徴とする請求項 2 記載のプラズマエッチング装置。

【請求項 4】 前記プラズマ源は、マグネトロン放電プラズマを形成するものであることを特徴とする請求項 2 記載のプラズマエッチング装置。

## 【発明の詳細な説明】

## 【0001】

【発明の属する技術分野】本願の発明は、磁性材料のエッチング技術に関するものであり、特に薄膜磁気ヘッドの製造に好適に利用されるエッチング技術に関するものである。

## 【0002】

【従来の技術】磁性材料をエッチングする技術は、磁気ディスクドライブに搭載される薄膜磁気ヘッドの製造等において重要な技術となっている。薄膜磁気ヘッドの製造では、フレイムメッキ法が多く用いられている。図 4 は、従来技術としてのフレイムメッキ法について説明する図である。まず、基板 90 の表面に所定のパターンでフレイムレジスト 901 を形成し（図 4（1））、フレイムレジスト 901 に対してメッキにより磁性薄膜 902 を形成する。（図 4（2））。そして、フレイムレジスト 901 の内側の磁性薄膜 902 を覆うようにして上部レジスト 903 を形成する（図 4（3））。この状態でエッチング液でウェットエッチングしてフレイムレジスト 901 の外側の磁性薄膜 902 を除去し、その後上部レジスト 903 及びフレイムレジスト 901 を剥離する。この結果、所定のパターンの磁性薄膜 902 が得られる（図 4（4））。

【0003】このようなフレイムメッキ法に対しては、

磁気ディスクの高密度化に伴う薄膜磁気ヘッドの微細化を背景として、その限界が指摘されている。フレイムメッキ法では厚いフレイムレジストの形成が必要であるが、微細なパターンではその形成が困難となるからである。

【0004】このような状況のもと、磁性薄膜をドライエッチング法により直接エッチングして所定のパターンの磁性薄膜を得ることが検討されている。一つの方法は、磁性薄膜にイオンを入射させてエッチングする方法である。例えば、アルゴンガスのプラズマからイオンを入射させたり、アルゴンのイオンビームを照射するなどしてエッチングすることが考えられる。しかしながら、このような方法は物理エッチングであり、下地やマスク等の他の材料に対する選択性が悪い。また、エッチング速度も一般的に低く、生産性の点で問題がある。

【0005】そこで、化学エッチングとして、反応性イオンエッチング（Reactive Ion Etching, RIE）をこの種の磁性材料のエッチングに応用することが検討されている。RIE による磁性材料のエッチングについては、例えば、J. Vac. Sci. Technol. A4(4), 1841(1986)や、Appl. Phys. Lett. 67(21), 3194(1995)で報告されている。しかしながら、これらの報告では、エッチング速度は  $10 \text{ nm/分}$  以下と低い。

【0006】近年になって、Appl. Phys. Lett. 71(9)1255(1997)等に、塩素ガスを用いることにより Ni-Fe 合金のエッチング速度  $300 \text{ nm/分}$  が得られた例が報告されている。しかしながら、塩素ガスによる磁性材料のエッチングでは、アフターコロージョンつまり表面に塩素が残留することによる腐食の問題が発生しがちである。アフターコロージョンは、エッチング後に水で洗浄する等の処理を行うことにより防止できるが、工程数が増大する問題がある。

【0007】アフターコロージョンの原因となる塩素やフッ素等を使用しないものとしては、特許第 2677321 号公報に開示された方法がある。この公報では、一酸化炭素 (CO) とアンモニア (NH<sub>3</sub>) を混合したガスを用いることにより、Ni-Fe 合金のエッチング速度  $35 \text{ nm/分}$ 、Co-Cr 合金のエッチング速度  $24.4 \text{ nm/分}$  がそれぞれ得られたとされている。

## 【0008】

【発明が解決しようとする課題】上述したように、CO と NH<sub>3</sub> の混合ガスを用いることで、アフターコロージョンの問題を招くことなく、薄膜磁気ヘッド等に適した Ni、Co 又は Fe より成る磁性薄膜をエッチングすることが可能である。しかしながら、そのエッチング速度は  $24 \sim 35 \text{ nm/分}$  程度であり、依然として低い。薄膜磁気ヘッドの製造では、 $2 \mu\text{m}$  の厚さのエッチングを行う必要がある。従って、現状のエッチング速度では  $50 \sim 80 \text{ 分}$  程度の時間を要することになり、実用化にはまだ遠い計算である。本願の発明は、このような状況

を考慮して成されたものであり、COとNH<sub>3</sub>の混合ガスを用いた磁性薄膜のエッチングにおいて、現状を遥かに越える高い速度でエッチングすることを可能にし、薄膜磁気ヘッド等の製造へのこの種の技術の実用化の途を開くという技術的意義を有する。

#### 【0009】

【課題を解決するための手段】上記課題を解決するため、本願の請求項1記載の発明は、ニッケル、鉄、コバルト、これらのうち少なくとも一つを含む合金、窒化物もしくは酸化物、又は、これらの少なくとも一つを含む金属間化合物から成る磁性材料である対象物の表面を臨む空間に、アンモニア及び一酸化炭素の混合ガスのプラズマを $1 \times 10^{11} \text{ cm}^{-3}$ 以上の密度で形成して、前記磁性材料である表面をエッチングするという構成を有する。また、上記課題を解決するため、請求項2記載の発明は、排気系を備えた処理チャンバーと、処理チャンバー内にアンモニアガス及び一酸化炭素ガスを混合して導入するガス導入系と、導入されたガスにエネルギーを供給してこれらのガスのプラズマを $1 \times 10^{11} \text{ cm}^{-3}$ 以上の密度で形成するプラズマ源と、表面がニッケル、鉄、コバルト、これらのうち少なくとも一つを含む合金、窒化物もしくは酸化物、又は、これらの少なくとも一つを含む金属間化合物から成る磁性材料である対象物をその表面が前記プラズマによってエッチングされる位置に保持する対象物ホルダーとを備えているという構成を有する。また、上記課題を解決するため、請求項3記載の発明は、上記請求項2の構成において、前記プラズマ源は、ヘリコン波プラズマを形成するものであるという構成を有する。また、上記課題を解決するため、請求項4記載の発明は、上記請求項2の構成において、前記プラズマ源は、マグネトロン放電プラズマを形成するものであるという構成を有する。

#### 【0010】

【発明の実施の形態】以下、本願発明の実施の形態について説明する。まず、請求項2及び請求項3の発明の実施形態について説明する。図1は、請求項2及び請求項3の発明の実施形態であるプラズマエッチング装置の概略構成を示す正面断面図である。

【0011】図1に示すプラズマエッチング装置は、ヘリコン波プラズマによって対象物の表面をエッチングする装置となっている。ヘリコン波プラズマは、比較的低い圧力でも高密度のプラズマが形成できるものとして注目されている。ヘリコン波プラズマにおけるエネルギー伝達のメカニズムは十分明らかになっていないところがあるが、ランダウ減衰と呼ばれる現象により高周波から電子に運動エネルギーが与えられることでプラズマが形成されると考えられている。即ち、磁界により回転しながら移動する電子の速度がヘリコン波の位相速度に等しいとき、電子から見てヘリコン波は止まっているのと同様なので、電子はヘリコン波から連続的に加速されてエ

ネルギーを吸収し、これによって高密度のプラズマが形成されるのである。

【0012】装置の構成について具体的に説明すると、図1に示す装置は、ヘリコン波プラズマを発生させるプラズマ源1と、プラズマ源1が発生させたプラズマが拡散する処理チャンバー2と、処理チャンバー2内にCO及びNH<sub>3</sub>の混合ガスを導入するガス導入系3と、処理チャンバー2内の所定位置にエッチングの対象物9を保持する対象物ホルダー4等から主に構成されている。

【0013】プラズマ源1は、処理チャンバー2に対して内部空間が連通するようにして気密に接続された誘電体容器11と、誘電体容器11内にヘリコン波を誘起するアンテナ12と、アンテナ12に供給する高周波電力を発生させるプラズマ用高周波電源13と、誘電体容器11内に所定の磁界を設定する磁石14等とから構成されている。誘電体容器11は、一端が開口であり他端が半球状に閉じている円筒状の部材であり、石英等で形成されている。処理チャンバー2の上壁部には開口が設けられており、誘電体容器11の一端の開口とこの上壁部の開口とを連通させるようにして誘電体容器11が処理チャンバー2に気密に接続されている。

【0014】プラズマ用高周波電源13は、例えば13.56MHzの高周波を発生させるものが使用される。アンテナ12は、棒状又は帯状の部材を丸めて両端を少し離間させたほぼ円環状の形状であって、誘電体容器11を取り囲むよう誘電体容器11と同軸上に配置されている。アンテナ12は誘電体容器11の軸方向に二つ設けられており、両者の両端部がそれぞれ中継ロッド121で電気的に接続されている。

【0015】プラズマ用高周波電源13とアンテナ12とは、不図示の整合器を介して同軸ケーブルのような伝送路15によって接続されている。プラズマ用高周波電源13が発生させた高周波が伝送路15によって二つのアンテナ12に供給された際、二つのアンテナ12には互いに逆向きの電流が流れるようになっている。この結果、誘電体容器11の内部に、ヘリコン波（ここでは、ホイスラー波と同様の右回りの円偏波）が誘起されるようになっている。尚、二つのアンテナ12の離間間隔は、電子の移動速度との関係においてヘリコン波の位相速度が最適になるように選定されている。

【0016】また、磁石14は、ヘリコン波の進行方向に平行な磁界を誘電体容器11内に設定するためのものである。磁界の強さは、誘電体容器11の中心軸付近で例えば100ガウス程度とされる。本実施形態では、磁石14は電磁石であり、同軸上に二つ設けられている。内側の磁石14は主にヘリコン波プラズマ形成のため、外側の磁石14は主に磁界形状の調整のために設けられている。

【0017】ガス導入系3は、COガスを溜めたボンベ31及びNH<sub>3</sub>ガスを溜めたボンベ31と、各ボンベ3



1 と処理チャンバー 2 とを繋ぐ配管 3 2 上に設けられたバルブ 3 3、流量調整器 3 4 及び不図示のフィルタ等から主に構成されている。CO ガス及び NH<sub>3</sub> ガスの混合比及び流量は、各流量調整器 3 4 によって調整できるようになっている。処理チャンバー 2 は、不図示のゲートバルブを備えた気密な真空容器である。処理チャンバー 2 に付設された排気系 2 1 は、拡散ポンプやターボ分子ポンプ等を備えて所定の到達圧力まで処理チャンバー 2 内を排気可能に構成される。

【0018】処理チャンバー 2 の側壁の外側には、図 1 に示すように多数の側壁用磁石 2 2 が設けられている。側壁用磁石 2 2 は、処理チャンバー 2 の側壁を臨む面の磁極が隣り合う磁石同士で互いに異なるよう周方向多数並べて配置されたものである。これらの側壁用磁石 2 2 により、処理チャンバー 2 の側壁の内面に沿ってカスプ磁場が周方向に連なって形成される。この結果、当該内面へのプラズマの拡散が防止されるようになっている。

【0019】また、本実施形態では、対象物 9 は板状のものが想定されている。対象物ホルダー 4 は、このような対象物 9 を上面に載置して保持する台状の部材である。対象物ホルダー 4 には、対象物 9 にセルフバイアス電圧を印加するためのバイアス用高周波電源 5 が設けられている。このバイアス用高周波電源 5 には、数 MHz から数 10 MHz 程度の周波数のものが使用され、プラズマと高周波との相互作用によって対象物 9 の表面に負の直流分の電圧であるセルフバイアス電圧を印加するよう構成されている。より具体的には、例えば 1.6 MHz や 13.56 MHz 程度の周波数のものがバイアス用高周波電源 5 として好適に使用可能である。尚、セルフバイアス電圧の印加のためには、対象物 9 が直流的にアースから絶縁される必要があり、このため、バイアス用高周波電源 5 と対象物ホルダー 4 との間にコンデンサが配置される場合がある。対象物ホルダー 4 内には、対象物 9 を加熱又は冷却しながら対象物 9 の温度を所定の値に制御する温度制御機構 4 1 が設けられている。そして、対象物 9 と対象物ホルダー 4 の上面との間に、He 等の熱伝導性の良好なガスを供給する不図示の熱伝導用ガス供給系が設けられている。

【0020】次に、請求項 1 の磁性材料のエッチング方法の発明の実施形態の説明も兼ねて、上記構成の装置の動作について説明する。まず、対象物 9 の表面は、ニッケル、鉄、コバルト、これらのうち少なくとも一つを含む合金、窒化物もしくは酸化物、又は、これらの少なくとも一つを含む金属間化合物から成る磁性材料となっている。このような対象物 9 は、所定圧力に排気されている不図示の真空補助チャンバー内に位置している。処理チャンバー 2 内が排気系 2 1 によって真空補助チャンバーと同程度まで排気されていることを確認すると、不図示のゲートバルブが開いて対象物 9 が処理チャンバー 2 内に搬入され、対象物ホルダー 4 に保持される。対象物

9 は、温度制御機構 4 1 により所定の温度に維持される。

【0021】次に、ガス導入系 3 が動作して、CO ガス及び NH<sub>3</sub> ガスを所定の混合比及び流量で処理チャンバー 2 内に導入する。導入されたガスは、処理チャンバー 2 内を経由して誘電体容器 1 1 内に拡散する。そして、プラズマ源 1 が動作してプラズマが形成される。即ち、プラズマ用高周波電源 1 3 からアンテナ 1 2 に高周波が供給され、前述したようにヘリコン波が誘起される。この結果、ヘリコン波のエネルギーがガスに与えられてヘリコン波プラズマが形成される。同時にバイアス用高周波電源 5 を動作させ、対象物 9 に負の直流分の電圧であるセルフバイアス電圧を与える。

【0022】形成されたプラズマは、誘電体容器 1 1 から処理チャンバー 2 内に拡散し、対象物 9 の表面付近にまで達する。この際、プラズマ中の生成物の作用により、対象物 9 の表面がエッチングされる。所定時間エッチングを行った後、ガス導入系 3、プラズマ源 1 及びバイアス用高周波電源 5 の動作を止め、処理チャンバー 2 内を再度排気した後、対象物 9 を処理チャンバー 2 から取り出す。

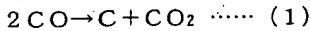
【0023】上記動作におけるエッチングのメカニズムについて、具体的に説明する。上述した CO と NH<sub>3</sub> の混合ガスから成るプラズマ中では、CO の活性種が生成される。この CO 活性種が、対象物 9 の表面の Ni、Fe 又は Co と反応し、Ni(CO)<sub>4</sub>、Fe(CO)<sub>5</sub> 又は Co<sub>2</sub>(CO)<sub>8</sub> のようなカルボニル化合物が生ずる。一方、セルフバイアス電圧が与えられている対象物 9 の表面には、プラズマからイオンが引き出されて入射する。このイオン入射の衝撃により、表面のカルボニル化合物が蒸発する。

【0024】ニッケル、鉄、コバルト等の遷移金属は、一般的には反応性エッチングによっても充分な速度でエッチングするのは困難である。つまり、ニッケル、鉄、コバルト等の遷移金属の塩化物やフッ化物は揮発性が低かったり（飽和蒸気圧が低かったり）、結合エネルギーが大きかったりするため、塩素系ガスやフッ素系ガスを使用して塩化物やフッ化物を生じさせても容易にはエッチングできない。尚、ここで言及した「結合エネルギー」は、そのような遷移金属の化合物の分子間に働く結合エネルギーのことを意味している。

【0025】一方、カルボニル化合物は、これらの遷移金属の化合物の中でも揮発性の高い（又は結合エネルギーの小さい）数少ない化合物である。上述したように、CO 活性種によってカルボニル化合物が生成された磁性材料の表面は、プラズマ中のイオンの入射によって蒸発する。このようなメカニズムにより、本実施形態の装置及び方法におけるエッチングは成される。尚、この際のカルボニル化合物の蒸発は、スパッタエッチングと呼び得るもの場合もあるし、単にイオン入射によって与えら

れたエネルギーにより加熱されて蒸発する場合もあると考えられる。

【0026】また、COガスに混合されるNH<sub>3</sub>ガスは、上記CO活性種によるカルボニル化合物の生成を促進する作用を有する。上述したようにプラズマ中でCO活性種が生成され、これによって磁性材料の表面にカルボニル化合物が形成されるものの、プラズマ中では、以下の式(1)に示すように、COが炭素と二酸化炭素に分解する不均等化反応が進行する。



混合されたNH<sub>3</sub>ガスは、この式(1)の不均等化反応を抑制する働きがある。不均等化反応が抑制される結果、COが失われることなく、CO活性種を豊富に生成することができる。これにより、上述した高い速度のエッチングが維持される。

【0027】上記動作において、プラズマ源1は、ヘリコン波プラズマを形成するものであり、そのプラズマ密度は $1 \times 10^{11} \text{ cm}^{-3}$ 以上となっている。この構成は、この種のエッチングにおけるエッチング速度とプラズマ密度との関係について研究した発明者の研究成果に基づくものである。この点について、以下に説明する。図2は、エッチング速度とプラズマ密度との関係について調べた実験結果を示す図である。この図2に示す実験では、図1に示す装置を使用し、磁性材料としてNi-Fe合金をエッチングした。プラズマ密度は、処理チャンパー2内の圧力、ガス流量、プラズマ源1のプラズマ用高周波電源13の出力等を調整して変化させた。また、プラズマ密度は、図1に示す装置において、対象物9の中心軸上で対象物9の表面から20mmの高さの位置における値をラングミュアプローブにより測定した。

【0028】尚、プラズマ密度が変化すると、バイアス用高周波電源5の周波数や出力が同じでもセルフバイアス電圧の大きさが変わってしまう。セルフバイアス電圧はイオン入射用の電界をもたらしものであるから、セルフバイアス電圧が変化してしまうと、対象物9の表面のイオン衝撃の強さも変化してしまう。プラズマ密度の変化がエッチング速度にどのような影響を与えるかを純粋に調べるためには、イオン衝撃の強さを一定にしなければならない。このようなことから、この図2に示す実験においては、バイアス用高周波電源5の出力を調整しながらプラズマ密度を変化させ、プラズマ密度の変化にかかわらず一定のセルフバイアス電圧になるようにした。

【0029】図2に顕著に示されているように、プラズマ密度 $1 \times 10^{11} \text{ cm}^{-3}$ を境にしてエッチング速度が急激に上昇している。この点の原因は、プラズマの状態がプラズマ密度 $1 \times 10^{11} \text{ cm}^{-3}$ を境にして変化することにあるものと推察される。つまり、プラズマ密度 $1 \times 10^{11} \text{ cm}^{-3}$ を境にして、質量の大きなCOイオンが飛躍的增多することが原因であると推察される。

【0030】より具体的に説明すると、上述したような

プラズマ源1によってプラズマが形成された際、導入されたガスが全てプラズマ化している(イオンと電子に電離している)訳ではなく、相当数の中性ガス分子が存在している。プラズマ用高周波電源13の出力を上昇させて供給するエネルギーを多くすると、電離するガスが多くなってプラズマ密度が高くなり、その分、中性ガス分子が少なくなる。ここで、供給エネルギーの少ないうちは、イオン化エネルギーの低いNH<sub>3</sub>ガスが支配的に電離する。そして、供給エネルギーが多くなると、イオン化エネルギーの高いCOガスも多く電離するようになる。COはNH<sub>3</sub>よりも質量が大きいため、イオン衝撃した際のエネルギーもNH<sub>3</sub>より高い。プラズマ密度 $1 \times 10^{11} \text{ cm}^{-3}$ を境にして、エッチング速度が急激に上昇するのは、質量の高いCOイオンの入射が急激に多くなる結果であると推察されるのである。本実施形態の装置及び方法は、このような実験の結果を踏まえ、 $1 \times 10^{11} \text{ cm}^{-3}$ 以上の高密度プラズマを形成してエッチングを行う構成とされている。このため、従来に比べてエッチング速度が飛躍的に向上し、厚い磁性薄膜でも短時間にエッチングできる実用的な構成となる。

【0031】尚、プラズマ密度 $1 \times 10^{11} \text{ cm}^{-3}$ 以上の条件は対象物9の表面で達成されることが好ましいが、対象物9の表面とプラズマとの間にはいわゆるシースの状態となるため、対象物9の表面まで厳密な意味でプラズマが拡散することはない。従って、プラズマ密度 $1 \times 10^{11} \text{ cm}^{-3}$ 以上の条件は、対象物9の表面からシースの厚さ以上の距離離れた場所であるということになる。この種の装置の実用的な構成においては、対象物9の表面から20mm以上のところは通常はシースの領域には入らない。従って、対象物9の表面から20mm以上のところでプラズマ密度 $1 \times 10^{11} \text{ cm}^{-3}$ 以上という条件を設定することも可能である。また、エッチング中の対象物9の温度については、130℃以上とすることが好ましい。130℃より低いと、所定時間のエッチング終了後も対象物9の表面に残さ(エッチングされないで残った粒状物質)が発生するからである。

【0032】次に、請求項2及び請求項4の発明の実施形態であるプラズマエッチング装置について説明する。図3は、請求項2及び請求項4の発明の実施形態であるプラズマエッチング装置の概略構成を示す正面断面図である。

【0033】この図3に示す装置は、マグネトロン放電プラズマを形成してエッチングを行うようになっている。具体的に説明すると、図3に示す装置は、マグネトロン放電プラズマを発生させるプラズマ源1と、プラズマ源1が発生させたプラズマが拡散する処理チャンパー2と、処理チャンパー2内にCO及びNH<sub>3</sub>の混合ガスを導入するガス導入系3と、処理チャンパー2内の所定位置に対象物9を保持する対象物ホルダー4等から主に構成されている。プラズマ源1は、マグネトロン電極1

6と、マグネトロン電極16に電圧を印加してマグネトロン放電を生じさせる放電用電源17とから主に構成されている。

【0034】マグネトロン電極16は、対象物ホルダー4に対向するよう設けられた電極板18と、電極板18の背後に設けられた磁石ユニット19とから構成されている。磁石ユニット19は、柱状の中心磁石191と、中心磁石191を取り囲む周状の周辺磁石192と、中心磁石191及び周辺磁石192とを繋ぐヨーク193とから構成されている。尚、電極板18が設けられず、磁石ユニット19のみでマグネトロン電極16が構成される場合もある。放電用電源17には、高周波電源又は負の直流電源が使用される。中心磁石191と周辺磁石192との間には、図3に示すような磁力線194で代表される磁界が設定される。放電用電源17によって設定される電界はこの磁界に直交し、マグネトロン構造が達成される。磁界と電界との直交関係は、マグネトロン電極16の軸の周りに周状に連なった状態である。

【0035】図3に示す装置の動作について説明すると、ガス導入系3によってCOガス及びNH<sub>3</sub>ガスを所定の混合比及び流量で処理チャンバー2内に導入しながら、プラズマ源1を動作させる。即ち、放電用電源17によって電極板18に所定の電圧を印加する。この結果、導入されたガスに放電が生じる。この際、電子は磁界と電界との直交関係によってマグネトロン運動し、高効率で中性ガス分子をイオン化させる。この放電によってガスがプラズマ化し、マグネトロン放電プラズマが形成される。そして、前述したのと同様に、プラズマ中で生成されるCO活性種によって対象物9の表面にカルボニル化合物が形成され、このカルボニル化合物がイオン衝撃によって蒸発する。この際、対象物9にはバイアス用高周波電源5によってセルフバイアス電圧が与えられ、イオンが効率よく表面に入射する。

【0036】この第二の実施形態においても、プラズマ密度は $1 \times 10^{11} \text{ cm}^{-3}$ 以上であり、質量の大きなCOイオンが多く入射するため、従来に比べて飛躍的に高いエッチング速度が得られる。上述したプラズマ源1は、電子をマグネトロン運動させるため、このような高密度のプラズマを容易に形成することが可能である。

【0037】

【実施例】次に、上記実施形態のエッチング方法の実施例について説明する。まず、シリコンウェーハ上にNi-Fe合金薄膜をスパッタリングにより作成し、この上にチタン製のマスクパターンを形成したものが対象物9として用いられた。装置としては、第一の実施形態のものが使用された。対象物9を対象物ホルダー4上に保持し、その温度を150℃に維持した。そして、ガス導入系3によって、COガスを20SCCM（SCCMは0℃1気圧での気体の流量（立方センチメートル））、NH<sub>3</sub>ガスを20SCCMの流量で処理チャンバー2内に

導入した。また、排気系21によって処理チャンバー2内を0.8Paに維持した。この状態で、プラズマ用高周波電源13によって13.56MHz1500Wの高周波を供給し、 $1 \times 10^{11} \text{ cm}^{-3}$ の密度のプラズマを形成してエッチングを行った。この結果、80nm/分程度という極めて高い速度でNi-Fe合金薄膜がエッチングされた。また、マスクであるチタンのエッチング速度は、Ni-Fe合金のエッチング速度の1/9程度であり、選択性の点でも優れた結果が得られた。エッチング後、湿度40%の大気下に2週間放置してもアフターコーロジションは発生しなかった。

【0038】また、別の対象物9として、シリコンウェーハ上にFeN薄膜をスパッタリングにより作成し、この上にチタン製のマスクパターンを形成したものが用いられた。装置としては、同様に第一の実施形態のものが使用された。この対象物9の温度を170℃、COガスの流量を35SCCM、NH<sub>3</sub>ガスの流量を50SCCM、処理チャンバー2内の圧力を0.4Paとし、13.56MHz3000Wの高周波によって $5 \times 10^{11} \text{ cm}^{-3}$ 程度の密度のヘリコン波プラズマを形成してエッチングを行った。この結果、130nm/分という極めて高い速度でFeN合金がエッチングされた。

【0039】さらに、別の対象物9として、シリコンウェーハ上にNi-Fe-Co合金薄膜をスパッタリングにより作成し、この上にチタン製のマスクパターンを形成したものが用いられた。装置としては、第二の実施形態のものが使用された。この対象物9の温度を150℃、COガスの流量を20SCCM、NH<sub>3</sub>ガスの流量を70SCCM、処理チャンバー2内の圧力を2.6Paとし、13.56MHz800Wの高周波によって $2 \times 10^{11} \text{ cm}^{-3}$ 程度の密度のマグネトロン放電プラズマを形成してエッチングを行った。この結果、90nm/分という極めて高い速度でNi-Fe-Co合金がエッチングされた。

【0040】本願発明においてエッチングされる磁性材料は、Ni、Fe、Co、これらのうち少なくとも一つを含む合金、窒化物もしくは酸化物、又は、これらの一つを含む金属間化合物であればよく、前述したものには限定されない。例えば、センダスト合金（Fe-Al-Si合金）、非晶質合金、グラニュラー合金（Co-Al-O合金）等の磁性材料をエッチングすることができるとことができる。

【0041】また、プラズマ源1には、前述したヘリコン波プラズマを形成するものやマグネトロン放電プラズマを形成するもの以外であっても、 $1 \times 10^{11} \text{ cm}^{-3}$ 以上の密度のプラズマを形成することができるとのものがあれば、他の構成のものも使用できる。例えば、ECR（電子サイクロトロン共鳴）プラズマを形成するもの等である。さらに、エッチングプロセスの用途としては、前述した薄膜磁気ヘッドの製造の他、マイクロトランスやマ

イクロ磁気回路の製造等が挙げられる。

#### 【0042】

【発明の効果】以上説明した通り、本願の各請求項の方法又は装置によれば、従来に比べてエッチング速度が飛躍的に向上し、厚い磁性薄膜でも短時間にエッチングできる実用的な構成となる。

#### 【図面の簡単な説明】

【図1】請求項2及び請求項3の発明の実施形態であるプラズマエッチング装置の概略構成を示す正面断面図である。

【図2】エッチング速度とプラズマ密度との関係について調べた実験結果を示す図である。

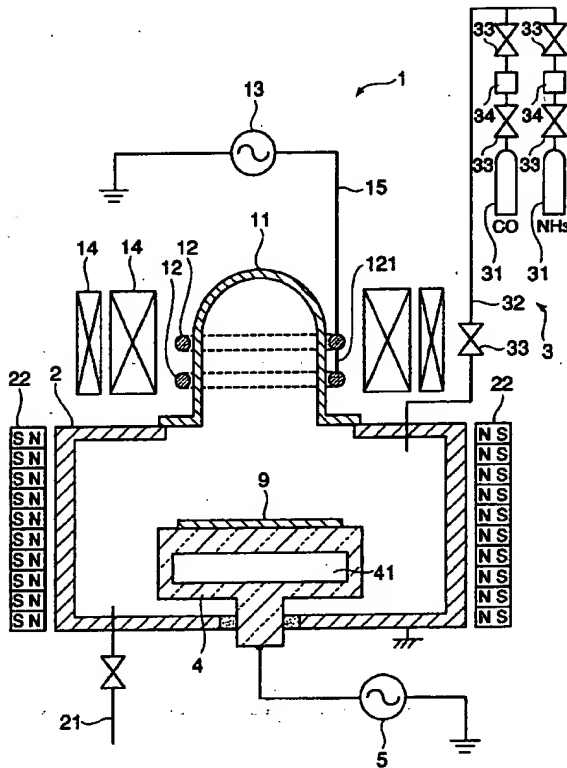
【図3】請求項2及び請求項4の発明の実施形態であるプラズマエッチング装置の概略構成を示す正面断面図である。

【図4】従来技術としてのフレームメッキ法について説明する図である。

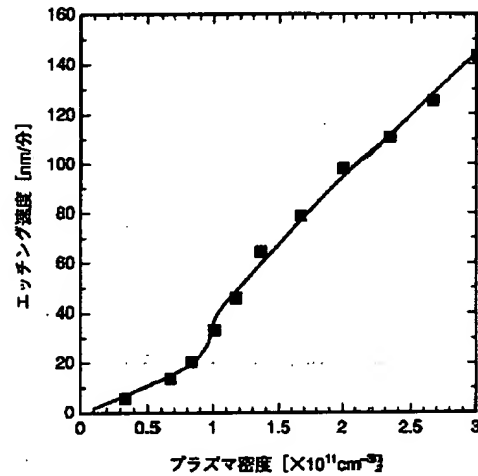
#### 【符号の説明】

- 1 プラズマ源
- 2 処理チャンバー
- 3 ガス導入系
- 4 対象物ホルダー
- 5 バイアス用高周波電源
- 9 対象物

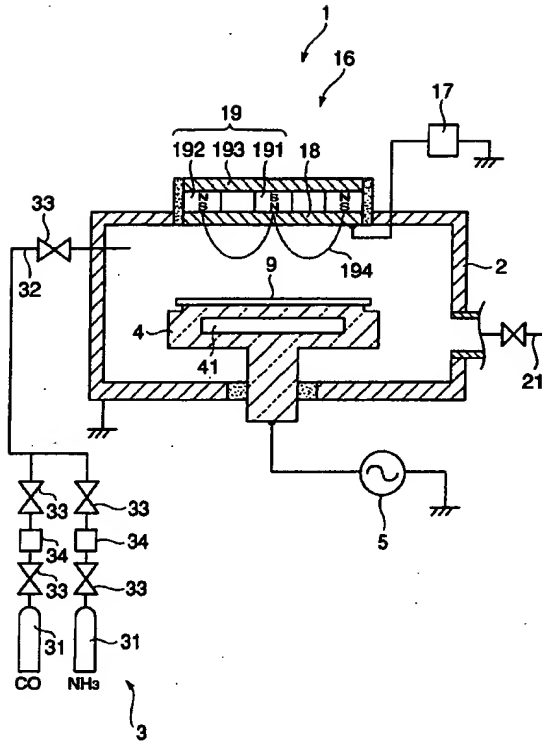
【図1】



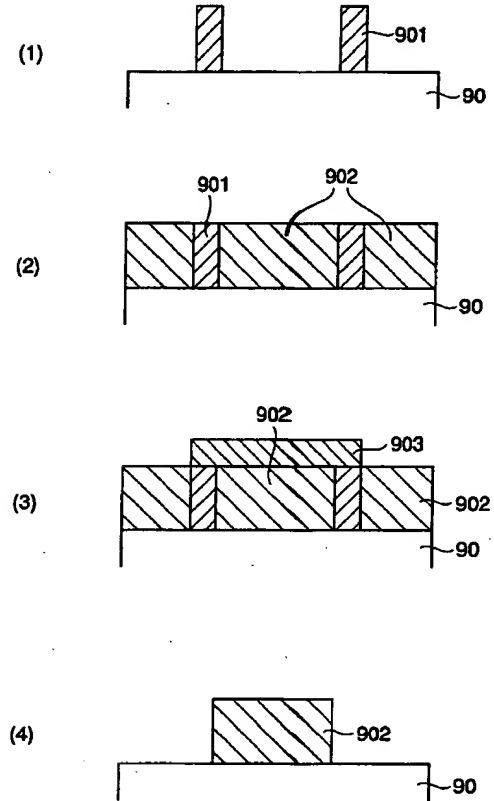
【図2】



【図3】



【図4】



フロントページの続き

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